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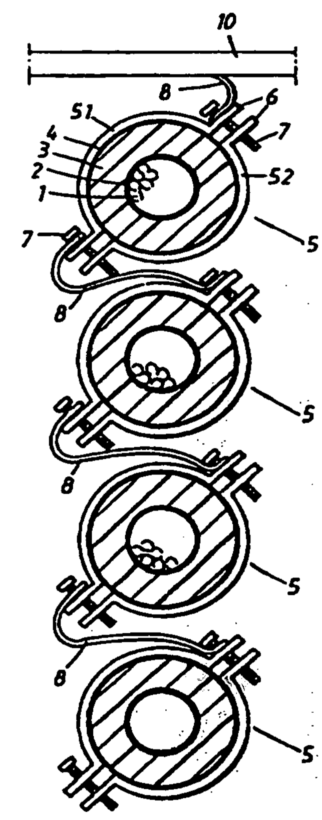
(54) Title: EARTHING DEVICE AND ROTATING ELECTRIC MACHINE INCLUDING THE DEVICE

(57) Abstract

In an electric machine including a core of one or more electric conductors (1) surrounded by insulating layers, comprising an inner semiconducting layer (2), an intermediate insulating layer (3) and an outer semiconducting layer (4), the outer semiconducting layer (4) is electrically connected to the earth reference (10) of the machine. For this purpose the outer semiconducting layer (4) is surrounded by a sheet metal earthing plate (5) which is clamped firmly around the outer semiconducting layer (4) by at least one earthing screw (7) and is in electrically conducting contact therewith. The sheet metal earthing plate (5) is electrically connected via an earth wire (8), preferably connected to the earthing screw (7), to said earth reference (10). In a stator winding to a high-voltage generator each winding part is provided with at least one sheet metal earthing plate (5), the sheet metal earthing plates in the various winding parts being electrically connected in series to the earth reference (10).



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EARTHING DEVICE AND ROTATING ELECTRIC MACHINE INCLUDING THE DEVICE

TECHNICAL FIELD OF THE INVENTION

The present invention relates to a device for earthing insulated conductors in an electric machine of the type described in the preamble to claim 1.

The invention also relates to a rotating electric machine according to the preamble of claim 10.

The types of machines in question may be for instance synchronous machines, double-fed machines, applications in asynchronous static current converter cascades, outer pole machines and synchronous flux machines, as well as alternating current machines.

The machine and the device are intended primarily as and for a generator in a power station for generating electric power. The machine and the device are intended for use with high voltages.

High voltages shall be understood here to mean primarily electric voltages in excess of 10 kV. A typical operating range may be 36 to 800 kV, preferably 72,5 -800 kV.

The magnetic circuit referred to in this context comprises a magnetic core of laminated, non-oriented or oriented, sheet or other material, for example amorphous or powder-based, or any other arrangement for the purpose of allowing an alternating magnetic flux, a winding, a cooling system, etc., and which may be arranged in the stator of the machine, in the rotor or in both.

BACKGROUND OF THE INVENTION

A general endeavor in the concerned types of machines is to

keep the outer insulating layer of insulated conductors/cables close to earth potential. This can naturally be achieved through the attachment points for suspending the cables at the distribution network or for attachment of the cable when used in or in connection with various electrical machines.

Known stator windings for generators are traditionally manufactured so that their outer surfaces are kept at earth potential within the laminated stack but far out in the region of their end windings the surface potential is permitted to float. Normally the stator windings of known generators are earthed with high resistance.

Machines of the type in question have conventionally been designed for voltages in the range 6-30 kV, and 30 kV has normally been considered to be an upper limit. This usually means that a generator must be connected to the power network via a transformer that steps up the voltage to the power network level - in the range of approximately 100-400 kV.

During the last decades, there have been increasing demands for rotating electric machines for higher voltages than what has previously been possible to design. The maximum voltage level which, according to the state of the art, has been possible to achieve for synchronous machines with a good yield in the coil production is around 25-30 kV. It is also commonly known that the connection of a synchronous machine/generator to a power network must take place via a Δ/Y-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Thus, this transformer, and the synchronous machine, constitute integral parts of an installation. The transformer constitutes an extra cost and also has the disadvantage that the total efficiency of the system is reduced. If it were possible to manufacture machines

for considerably higher voltages, the step-up transformer could thus be omitted.

Attempts to develop the generator for higher voltages have, however, been in progress for a long time. This is obvious, for instance from "Electrical World", October 15, 1932, pages 524-525. This describes how a generator designed by Parson 1929 was arranged for 33 kV. It also describes a generator in Langerbrugge, Belgium, which produced a voltage of 36 kV. Although the article also speculates on the possibility of increasing voltage levels still further, the development was curtailed by the concepts upon which these generators were based. This was primarily because of the shortcomings of the insulation system where varnish-impregnated layers of mica oil and paper were used in several separate layers.

Certain attempts to a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US 4,429,244 "Stator of Generator" and in Russian patent document CCCP Patent 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots, made with rectangular cross section, by means of wedges. As coolant, oil is used both in the hollow conductors

and in holes in the stator walls. Such cooling systems, however, entail a large number of connections for both oil and electricity at the end windings. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need of insulation of the stator winding is less towards the interior of the rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder or ring nearest the inner surface of the core which may increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. What is special for the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centred, inside an insulation sleeve. The conductors of the stator winding are cooled by surrounding oil. The disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulation sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the purpose of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional insulated conductor

for medium voltage with the same dimension for all the layers. The conductor is placed in stator slots formed as circular, radially disposed openings corresponding to the cross-section area of the conductor and with the necessary space for fixation and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulated tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the coolant against the internal air gap. The design shown has no tapering of the insulation or of the stator slots. The design exhibits a very narrow radial waist between the different stator slots, which means a large slot leakage flux which significantly influences the magnetization requirement of the machine.

In a report from the Electric Power Research Institute, EPRI, EL-3391 from April 1984, an account is given of generator concepts for achieving higher voltage in an electric generator with the object of being able to connect such a generator to a power network without intermediate transformers. Such a solution is assessed in the report to offer good gains in efficiency and considerable financial advantages. The main reason that it was deemed possible in 1984 to start developing generators for direct connection to power networks was that a superconducting rotor had been developed at that time. The considerable excitation capacity of the superconducting field winding enables the use of airgap-winding with sufficient thickness to withstand the electrical stresses.

By combining the concept deemed most promising according to the project, that of designing a magnetic circuit with winding, known as "monolith cylinder armature", a concept in which two cylinders of conductors are enclosed in three cylinders of insulation and the whole structure is attached to an iron core without teeth, it was assessed that a rotating electric machine for high-voltage could be directly connected

to a power network. The solution entailed the main insulation having to be made sufficiently thick to withstand network-to-network and network-to-earth potentials. Obvious drawbacks with the proposed solution, besides its demand for a superconducting rotor, are that it also requires extremely thick insulation, which increases the machine size. The end windings must be insulated and cooled with oil or freons in order to control the large electric fields at the ends. The whole machine must be hermetically sealed in order to prevent the liquid dielectric medium from absorbing moisture from the atmosphere.

SUMMARY OF THE INVENTION

The object of the present invention is to solve the above mentioned problems and to provide a device for earthing insulated conductors or cables in an electric machine, in particular an electric machine which permits direct connection to all types of high-voltage power networks, as well as to provide such a rotating electric high-voltage machine.

This object is achieved by providing a device for earthing insulated conductors in an electric machine, as defined in the introductory part of claim 1, with the advantageous features of the characterizing part of said claim, and by providing a rotating electric machine in accordance with the introductory of claim 10 with the advantageous features of the characterizing parts of said claim.

Accordingly, the device is charcterized in that the insulated conductor comprises a central part composed of one or more electric conductors, which central part is surrounded by several layers comprising an inner semiconducting layer, an intermediate insulating layer and an outer semiconducting layer, and that the outer semiconducting layer of the insulated conductor is electrically connected to the earth

reference of the machine via one or more sheet metal earthing plates connected thereto.

By using high-voltage insulated electric conductors, also referred to as cables, with permanent insulation similar to that used in cables for transmitting electric power (e.g. crosslinked polyethylene (XLPE) cables), the machine has the important advantage that the voltage can be increased to such levels that it can be connected directly to the power network without an intermediate transformer.

The cable is provided with an outer semiconducting layer with the aid of which its potential in relation to the surroundings shall be defined. This layer must therefore be connected to earth, at least somewhere in the machine, possibly only in the end-winding section.

In order to serve its purpose as earth connection, the outer semiconducting layer should have low resistance. On the other hand heat losses will then occur due to magnetically induced currents, which means that its coherent length must perhaps be limited.

The demands placed by high voltages on the cable in the stator winding of a high-voltage generator cannot be satisfied with the arrangements described for conventional low-voltage generators. The known arrangements would entail problems with high magnetically induced currents in the outer semiconducting layer of the cable, resulting in considerable losses. Since the cable is in the form of a cylindrical capacitor, capacitive currents are also generated in the outer semi-conducting layer, which contribute to aggravating the problem just mentioned. It is therefore vital that the cable sheath of the electric machine has earth potential throughout.

This is achieved according to the present invention in that the outer semiconductor of the cable is electrically connected to the earth reference of the machine via sheet metal earthing plates. These earthing plates are preferably separate elements and are removably connected both to the insulated conductor and the earth potential.

Through the earthing device according to the invention the advantage is obtained of ensuring reliable and uniform earthing of the entire length of cable in electric machines, particularly in generators for voltages within the range 36 - 800 kV.

According to a particularly advantageous feature, a simple and effective solution to the problems listed is achieved with sheet metal earthing plates in the form of annular mechanical joints. As another feature, in a high-voltage generator of the type described above, these mechanical joints in the stator winding can be connected in series to the stator frame of the generator, either directly or via a circular earth bar.

As regards the rotating electric machine according to the present invention, it is characterized in that the machine is provided with the claimed earthing device. It is further characterized in that the winding comprises at least one current-carrying conductor, that a first layer having semiconducting properties is provided around said conductor, that a solid insulating layer is provided around said first layer, and that a second layer having semiconducting properties is provided around said insulating layer.

To be able to cope with the problems which arise in case of direct connection of rotating electric machines to all types of high-voltage power networks, a machine according to the invention may have a number of features which significantly distinguishes it from the state of the art both as regards

conventional mechanical engineering and the mechanical engineering which has been published during the last few years. Some will follow below.

As mentioned, the winding is manufactured from one or more insulated conductors with an inner and an outer semiconducting layer, preferably an extruded cable of some sort. Some typical examples of such conductors are a cable of XLPE or a cable with ethylene propylene (EP) rubber insulation, which, however, for this purpose and according to the invention, has an improved design both as regards the strands of the conductor and as regards the outer layer.

The use of an insulated conductor with an outer semiconducting layer has the advantage that it permits the outer layer of the winding, in its full length, to be maintained at earth potential. Consequently, the claimed invention may have the feature that the outer semiconducting layer is connected to earth potential. As an alternative, the outer layer may be cut off, at suitable locations along the length of the conductor, and each cut-off part length may be directly connected to earth potential.

A considerable advantage with having the outer or second layer connected to earth potential is that the electric field will be near zero in the end-winding region outside the outer semiconductor and that the electric field need not be controlled. This means that no field concentrations can arise, neither within the sheet, nor in the end-winding region, nor in the transition therebetween.

As another advantageous feature at least two, and preferably all three, of the layers have substantially equal thermal expansion coefficients. Through this is achieved that thermal movement is prevented and the occurrence of cracks, fissures

or other defects in the winding due to thermal movement is avoided.

According to another characterizing feature each of the three layers is solidly connected to the adjacent layer along substantially the whole connecting surface. This has the advantage that the layers are fixed and unable to move in relation to each other and serves to ensure that no play occurs between the layers. It is very important that no air is allowed to enter in-between the layers since that would lead to disturbances of the electric field.

As yet another advantageous feature the present invention is characterized in that the current-carrying conductor comprises a number of strands, only a minority of said strands being uninsulated from each other. The uninsulated strand or strands in the outer layer of the conductor defines the potential on the inner semiconducting layer and thereby ensures a uniform electric field within the insulation. By using uninsulated strands instead of insulated strands a less expensive insulated conductor for a winding is obtained. Theoretically, every second strand may be uninsulated, but for practical reasons the number of uninsulated strands is less than the insulated strands.

As an alternative, the winding may be formed of a cable comprising at least one current-carrying conductor and the machine is further characterized in that each conductor comprises a number of strands, that an inner semiconducting layer is provided around each conductor, that an insulating layer of solid insulating material is provided around said inner semiconducting layer, and that an outer semiconducting layer is provided around said insulating layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The earthing device according to the present invention will be described in more detail with reference to the accompanying drawings in which

- Figure 1 illustrates the principle of the earthing device in conjunction with one embodiment of the sheet metal earthing plates used,
- Figure 2 reveals an alternative embodiment of the sheet metal earthing plates,
- Figure 3 shows a direct connection of the earthing of the stator winding to the stator frame in a high-voltage generator according to the invention,
- Figure 4 shows the earthing of the stator winding through the connection of the end windings to a circular earth bar mounted in the stator frame in a high-voltage generator according to the invention, and
- Figure 5 is a cross section through an insulated conductor/cable for which the invention is applicable.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The cable in the shown machine constitutes the stator windings where each penetration of the cable through a stator slot is designated a coil side, and a loop of cable connecting two coil sides outside one of the ends of the stator is designated a coil end.

As can be seen in Figures 1 and 2, in a preferred embodiment of the earthing device according to the present invention each of the sheet metal earthing plates 5 is in the form of a hose clamp. Each end winding of a cable in the stator winding of a high-voltage generator, comprising a copper conductor 1 surrounded by an inner semiconducting layer 2, an intermediate insulating layer (XLPE) 3 and an outer semiconducting layer 4, is thus connected to at least one sheet metal earthing plate 5.

The sheet metal earthing plate 5 according to a preferred embodiment shown in Figure 1 comprises two clamping strips 51, 52 facing each other. Each identical clamping strip 51, 52 is bent to a semi-cylindrical form to fit the outer diameter of the cable it is to surround. The outer ends of the clamping strips 51, 52 are in the form of lugs or flanges 6 in which a hole is provided for an earthing screw 7. Besides providing connection for an earth wire 8, the earthing screw 7 serves as tightening device so that when the sheet metal earthing plate 5 is fitted on the cable it will clamp firmly around the cable and be in electrically conducting contact with the outer semiconducting layer 4 of the cable. To ensure cooperation between the earthing screw 7 and the sheet metal earthing plate 5, at least the flange part 6 facing away from the head of the earthing screw 7 may be in screw cooperation with the earthing screw 7 either by its aperture being threaded or by being supported by a nut.

An alternative embodiment of the sheet metal earthing plate 5 is shown in Figure 2, where the clamping strip 53 consists of a flexible ring applied on the cable part, after which the earthing screw 7 is inserted into the holes of the flange parts 6 to clamp the annular clamping strip 53 around the cable part.

As can be seen in Figures 1 and 2 each individual sheet metal earthing plate 5 is mounted on a coil end of the stator winding which, for the sake of simplicity, is only indicated by a cross section through a cable part. The sheet metal earthing plates 5 are connected in series by earth wires 8, the outermost being electrically connected to an earth bar 10.

The sheet metal earthing plates 5 are made of electrically conducting material, preferably material having good spring properties, e.g. phosphor bronze.

In the alternative embodiment of the sheet metal earthing plates 5 shown in Figure 2 it is advantageous for the screw 7 to be made of a material which is electrically non-conducting, in which case each electrically conducting earth wire 8 is connected to a flange part 6 as shown.

Figure 3 shows schematically a part of an electric high-voltage generator with a rotor R journalled on its rotor shaft A and surrounded by the stator S (of which only a section to the left of the rotor is shown in the figure). The laminated stack of the stator S is held together by a stator frame 9 and the end windings H of the stator winding protrude at the end of the stator S as indicated by two cut-off cable parts in the plane of the paper. In the manner described above in connection with Figures 1 and 2, these cable parts are each provided with a sheet metal earthing plate 5, said sheet metal earthing plates being electrically connected in series by means of earth wires 8 connected to the stator frame 9.

An alternative embodiment of the earthing of the end windings H is illustrated in Figure 4 showing the stator S seen in peripheral direction with the rotor shaft (not shown) in the vertical direction of the drawing. The sheet metal earthing plates 5 clamped on each cable part are electrically connected in series via the earth wires 8 to an earth bar 10 having circular form and attached to the stator frame (not shown).

As indicated by a copper conductor 11 which is mounted on the sheath (i.e. the outer semiconducting layer) of each cable part, and which is electrically connected to respective sheet metal earthing plates 5, protection can be achieved against an undesired increase in potential in the stator winding in the event of faults (earth faults) in the power network supplied by the high-voltage generator. The copper conductor 11 extends over substantially the entire cable part of the end winding situated outside the stator stack.

Resistance connected in the earth connection between the sheet metal earthing plate 5 and stator frame 9 may be of interest in damping any leakage currents.

Figure 5 shows a cross-sectional view of a high-voltage cable according to the present invention. The high-voltage cable comprises the (central) electric conductor 1 including a number of strands 18 of copper (Cu), for instance, having circular cross section. These strands 18 are arranged in the middle of the high-voltage cable. Around the strands 18 is a first semiconducting layer 2, and around the first semiconducting layer 2 is an insulating layer 3, e.g. XLPE insulation. Around the insulating layer 3 is a second semiconducting layer 4. Thus the concept "high-voltage cable" in the present application does not include the outer protective sheath that normally surrounds such cables for power distribution.

Although the present invention has been discussed in connection with a presently preferred embodiment having a certain type of sheet metal earthing plate illustrated in the drawings, it should be obvious to someone skilled in the art that the invention is not limited thereto but can be realized using other means. The sheet metal earthing plate may be replaced with more or less tightly wound coil-shaped bodies, for instance, which surround a part of each coil end and which are earthed in the manner described above.

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Patent claims

1. A device for earthing insulated conductors in an electric machine, **characterized** in that the insulated conductor comprises a central part composed of one or more electric conductors (1), which central part is surrounded by several layers comprising an inner semiconducting layer (2), an intermediate insulating layer (3) and an outer semiconducting layer (4), and that the outer semiconducting layer (4) of the insulated conductor is electrically connected to the earth reference (9, 10) of the machine via one or more sheet metal earthing plates (5) connected thereto.

2. A device as claimed in claim 1, **characterized** in that the insulated conductor is included in the stator winding of a rotating high-voltage machine with coil sides arranged in slots in the stator and coil sides connecting end windings situated outside the stator, said coil sides being insulated from the slots and sheet metal earthing plates being arranged at the end windings.

3. A device as claimed in claim 2, **characterized** in that each sheet metal earthing plates (5) consists of an annular clamp (51, 52; 53) arranged to surround the outer semiconductor (4) and exert pressure on the insulated conductor.

4. A device as claimed in claim 3, **characterized** in that the annular clamp (5) comprises two substantially semi-cylindrical clamping strips (51, 52) facing each other, the ends of each clamping strip terminating in a flange part (6) provided with an aperture for an earthing screw (7), said earthing screw (7) being arranged to contract the two clamping strips (51, 52) around the outer semiconductor (4) and to be connected to the earth reference (9, 10) of the machine via an electric conductor (8).

5. A device as claimed in any of claims 2-4, **characterized** in that each sheet metal earthing plate (5) is connected to the stator frame (9) and/or to a circular earth bar (10) mounted in the stator frame (9).

6. A device as claimed in claim 5, **characterized** in that the sheet metal earthing plates (5) are electrically connected in series with each other to the stator frame (9).

7. A device as claimed in any of claims 1-6, **characterized** in that the earthing is high-ohmic since a resistance is connected between the sheet metal earthing plates (5) and the earth reference (9, 10) of the machine.

8. A device as claimed in any of claims 1-7, **characterized** in that the sheet metal earthing plate (5) is electrically connected to an electric conductor (11) arranged on the surface of the outer semiconductor (4).

9. A device as claimed in any of claims 1-8, **characterized** in that the sheet metal earthing plate (5) is in the form of a coil wound around the outer semiconductor (4).

10. A rotating electric high-voltage machine including an insulated conductor, **characterized** in that the machine is provided with a earthing device as claimed in any of claims 1-9.

11. A rotating electric machine according to claim 10, **characterized** in that it is an electric high-voltage generator.

12. A rotating electric high-voltage machine according to claim 10 or 11 and comprising a stator, a rotor and at least one winding comprising an insulated conductor, **characterized** in that said insulated conductor comprises at least one

current-carrying conductor (1), that a first layer (2) having semiconducting properties is provided around said conductor, that a solid insulating layer (3) is provided around said first layer, and that a second layer (4) having semiconducting properties is provided around said insulating layer.

13. A rotating electric machine according to claim 12, **characterized** in that the potential of said first layer (2) is substantially equal to the potential of the conductor (1).

14. A rotating electric machine according to claim 12 or 13, **characterized** in that said second layer (4) is arranged to constitute a substantially equipotential surface surrounding said conductor.

15. A rotating electric machine according to claim 14, **characterized** in that said second layer is connected to a predetermined potential.

16. A rotating electric machine according to claim 15, **characterized** in that said predetermined potential is earth potential.

17. A rotating electric machine according to any one of claims 12-16, **characterized** in that at least two adjacent layers have substantially equal thermal expansion coefficients.

18. A rotating machine according to any one of claims 12-17, **characterized** in that said current-carrying conductor (1) comprises a number of strands (18), only a minority of said strands being uninsulated from each other.

19. A rotating electric machine according to any one of claims 13-18, **characterized** in that each of said three layers (2,3,4) is solidly connected to the adjacent layer along substantially the whole connecting surface.

20. A rotating electric machine according to claim 10 or 11 and having a magnetic circuit for high-voltage comprising a magnetic core and a winding, **characterized** in that said winding is formed of a cable comprising at least one current-carrying conductor (1) according to any one of claims 1-11, that each conductor comprises a number of strands (18), that an inner semiconducting layer (2) is provided around each conductor, that an insulating layer (3) of solid insulating material is provided around said inner semiconducting layer, and that an outer semiconducting layer (4) is provided around said insulating layer.

21. A rotating electric machine according to any one of claims 12-20, **characterized** in that said winding also comprises a metal shield and a sheath.

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Fig. 1

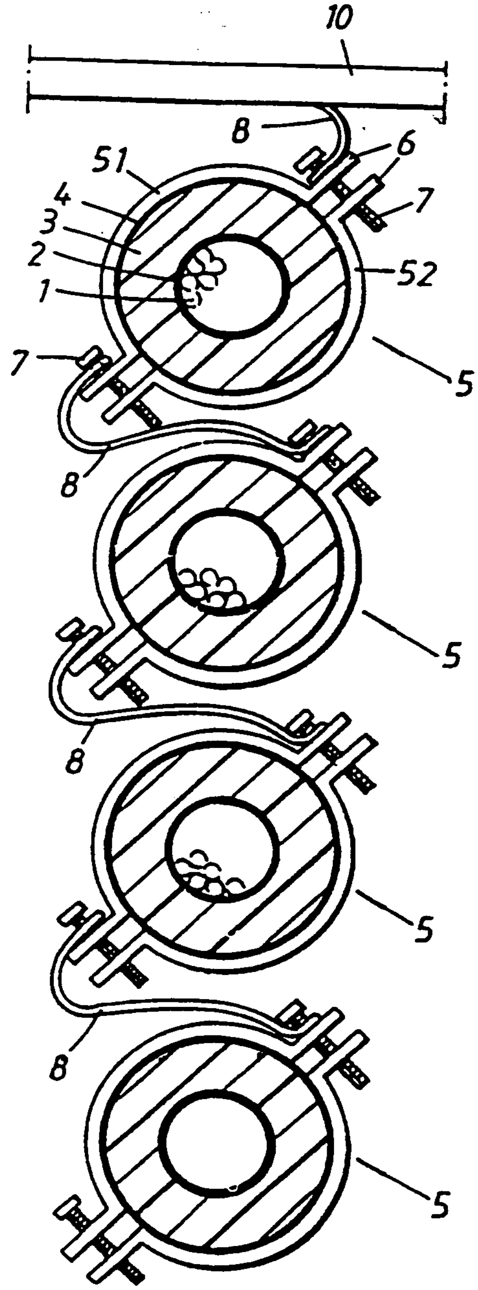

Fig. 2

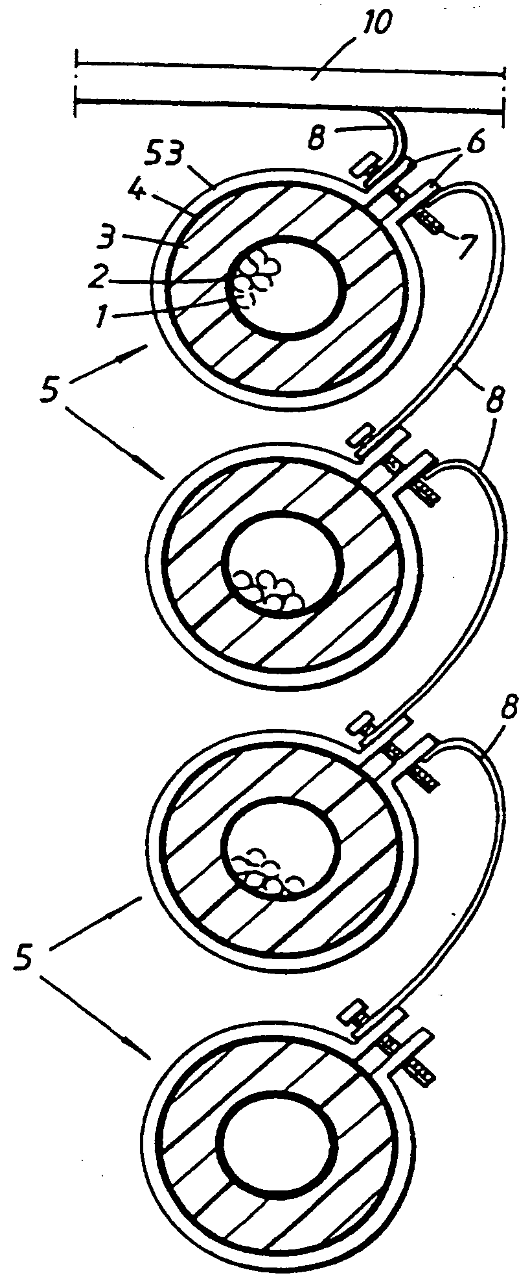

Fig. 3

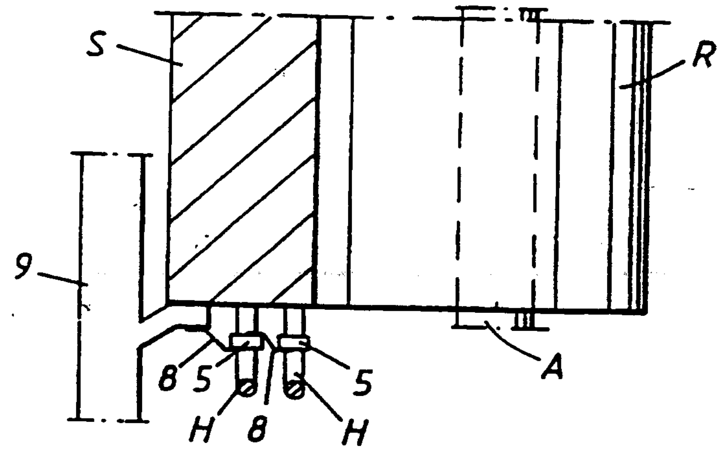

Fig. 4

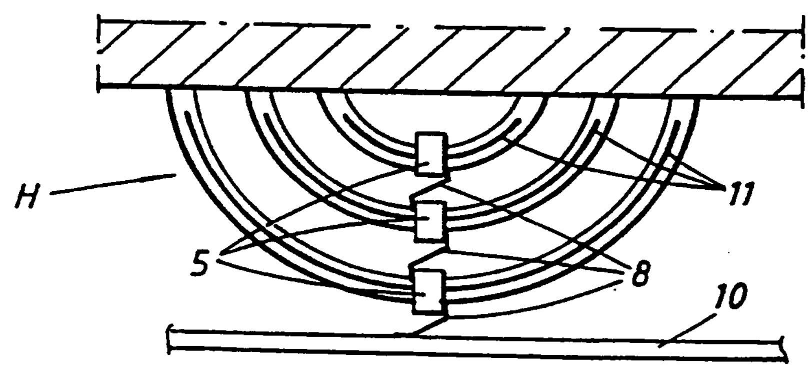

Fig. 5